# Probing the neutron skin and nuclear symmetry energy with isobar collisions at $\sqrt{s_{\rm NN}} = 200$ GeV by STAR

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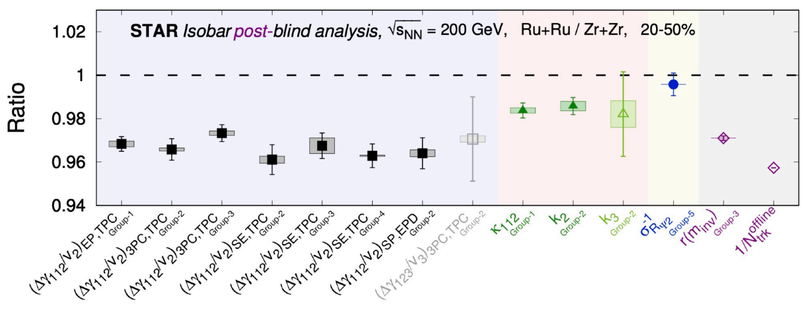
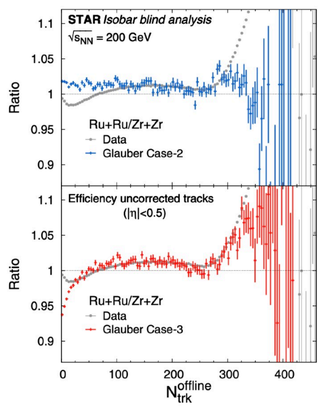
**Abstract:** The neutron skin thickness, $\Delta r_{\rm np}$, has traditionally been measured by low-energy hadron-nucleus and nucleus-nucleus scatterings over decades. Recent studies indicate that the neutron skin can also be measured, unconventionally and possibly with better precisions than traditional methods, by colliding isobar nuclei at relativistic energies. The idea is to compare the produced hadron multiplicities ($N_{\rm ch}$), the mean transverse momenta ($\langle p_T \rangle$), and the net charge multiplicities ($\Delta Q$) to trace back the nuclear structure differences between the isobar nuclei. In this poster, we will present results on the $N_{\rm ch}$, $\langle p_T \rangle$, and $\Delta Q$ ratios between ${}^{96}_{44}$Ru+${}^{96}_{44}$Ru and ${}^{96}_{40}$Zr+${}^{96}_{40}$Zr collisions at $\sqrt{s_{\rm NN}} = 200$ GeV by STAR. We extract the neutron skin thickness and the symmetry energy slope parameter from these data. We compare our results to the global data on symmetry energy and discuss their implications in the context of equation-of-state of dense matter and neutron stars.

## Relativistic isobar collisions:

STAR Collaborations, Phys.Rev. C105, 014901 (2022)



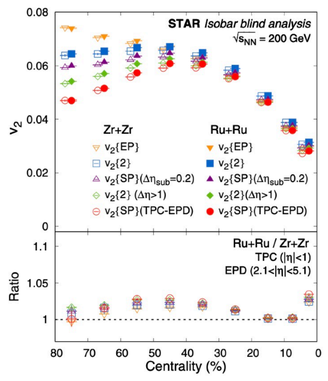




- Clear differences in multiplicity and elliptic flow, indicating isobar structure difference, moving the baseline from the original expectations of CME search in isobar collisions.

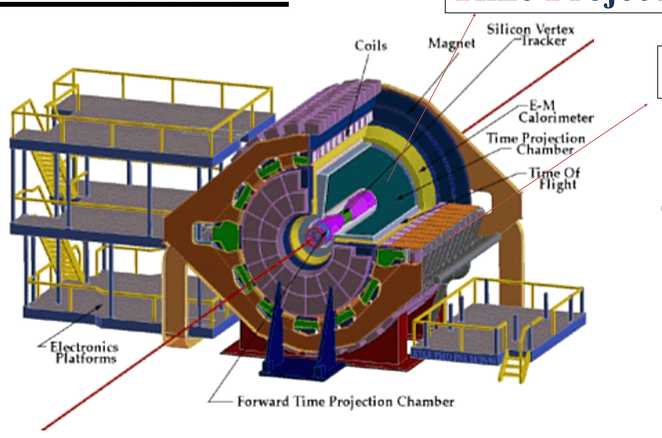
  HJX, et.al, Phys.Rev.Lett, 121, 022301 (2018)

- The STAR isobar data demonstrate **thick halo-type neutron skin in Zr,** consistent with energy density functional theory calculations.

  HJX, et.al, Phys.Lett. B819, 136453 (2021)



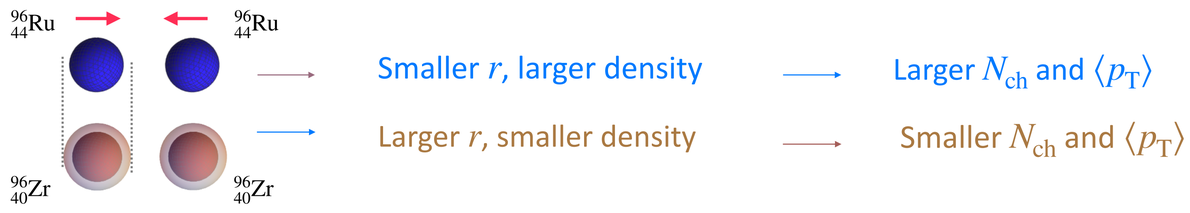

## STAR Detector:




## Acceptance:

- $|\eta| < 1$
- $0.2 < p_T < 2$ GeV/c
- $0 < \phi < 2\pi$

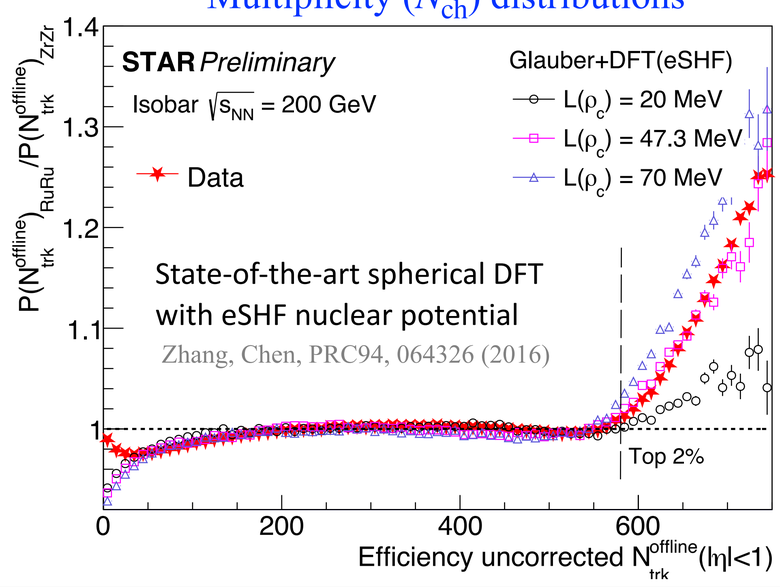
## Sensitive observables to probe the neutron skin




- Multiplicity distributions — H. Li, HJX, et.al, Phys.Rev.Lett., 125, 222301 (2020)
- Mean transverse momentum — HJX, et.al, arXiv:2111.14812
- Net charges (isospin sensitive) — HJX, et.al, Phys.Rev. C105, L011901 (2022)

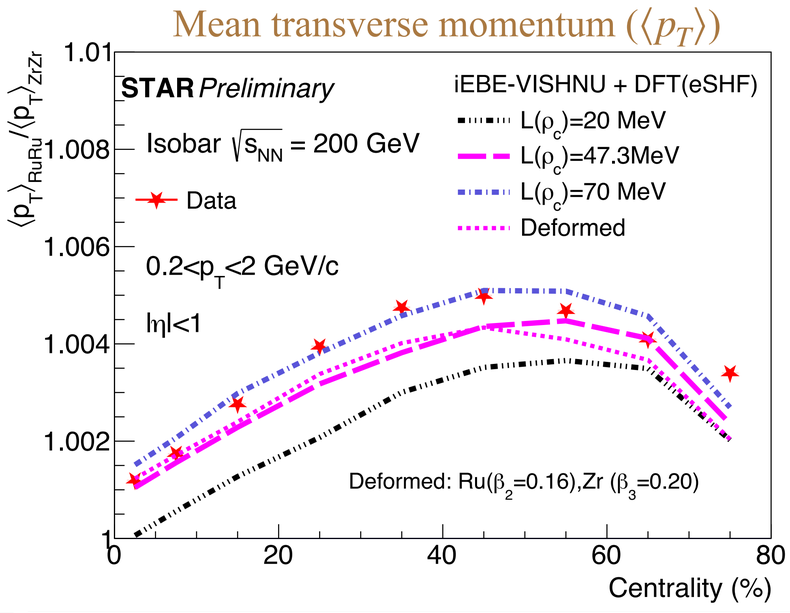
## Results:

### Multiplicity ($N_{\rm ch}$) distributions



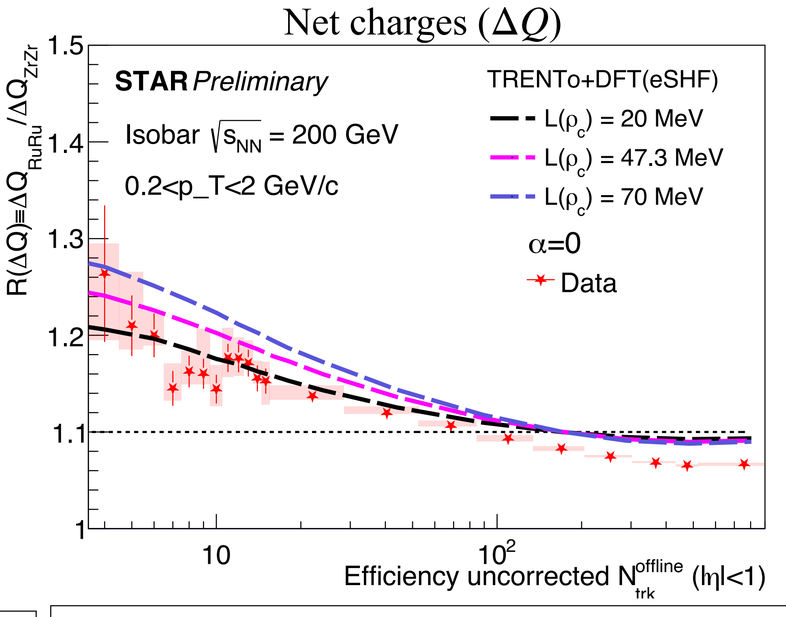

- $\langle N_{\rm ch} \rangle$ ratios in central collisions to extract $\Delta r_{\rm np}$ with linear interpolation
- $\Delta r_{\rm np,Zr} = 0.195 \pm 0.019$ fm
  $\Delta r_{\rm np,Ru} = 0.051 \pm 0.009$ fm
- Uncertainties dominated by nuclear deformation

### Mean transverse momentum ($\langle p_T \rangle$)




- $\langle p_T \rangle$ ratios in top 5% centrality to extract $\Delta r_{\rm np}$ with linear interpolation
- $\Delta r_{\rm np,Zr} = 0.202 \pm 0.024$ fm
  $\Delta r_{\rm np,Ru} = 0.052 \pm 0.012$ fm
- Uncertainties dominated by nuclear deformation

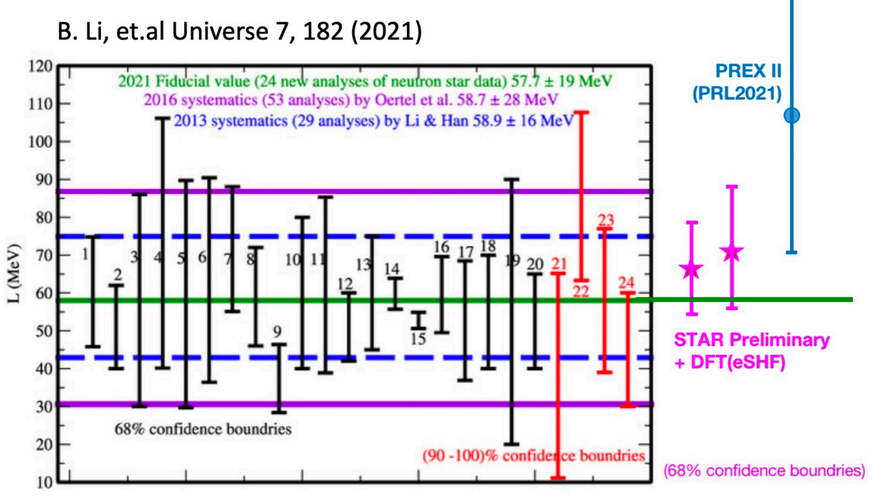
### Net charges ($\Delta Q$)




- $\Delta Q$ ratios in very peripheral collisions are directly related to $\Delta r_{\rm np}$ and $\alpha \equiv \Delta Q_{nn}/\Delta Q_{pp}$
- Data imply $\alpha \sim 0$, contrast to model studies $\alpha_{\rm model} \sim -0.3$

  HJX, et.al, Phys.Rev. C105, L011901 (2022)

## Compare to world wide data:




## Summary:

- The multiplicity and elliptic flow differences are crucial for the CME search in isobar collisions
- $\langle N_{\rm ch} \rangle$ and $\langle p_{\rm T} \rangle$ ratios in isobar collisions to probe **neutron skin and symmetry energy**
  - $L(\rho_c) = 53.8 \pm 1.7 \pm 7.8$ MeV from $\langle N_{\rm ch} \rangle$ ratio
  - $L(\rho_c) = 56.8 \pm 0.4 \pm 10.4$ MeV from $\langle p_{\rm T} \rangle$ ratio
  - Consistent with world wide data with good precision
- Net charge ratios in isobar collisions imply the $\alpha \equiv \Delta Q_{nn}/\Delta Q_{pp} \sim 0$, **contrast to model studies** $\alpha_{\rm model} \sim -0.3$, need further investigation.

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*The STAR Collaboration: http://drupal.star.bnl.gov/STAR/presentations*

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